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SPATIAL DISTRIBUTION OF THE SURFACE GEOLOGY AND 1992 LAND USE OF THE BUFFALO RIVER WATERSHED

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SIMULATION OF SEDIMENT AND NUTRIENT TRANSPORT IN THE BUFFALO RIVER WATERSHED USING A GEOGRAPHIC INFORMATION SYSTEM
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Kimberly R. Hofer
H. Don Scott
James M. McKimmey
Department of Agronomy
University of Arkansas
Fayetteville, Arkansas

Arkansas Water Resources Center
113 Ozark Hall
University of Arkansas
Fayetteville, Arkansas 72701

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Kimberly R. Hofer, H. Don Scott and James M. McKimmey

Department of Agronomy
University of Arkansas
Fayetteville, Arkansas

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INTRODUCTION

The Buffalo River was established by Congress in 1972 as the first National River in the United States and is one of the few remaining free-flowing streams in Arkansas. The Buffalo River flows through the three major physiographic provinces of northern Arkansas, originating in the higher elevations of the Boston Mountains, and flowing generally northeastward to cut through the Springfield and Salem Plateaus. It drops from approximately 2000 feet in the headwaters to around 500 feet above sea level at its confluence with the White River in Marion County. The Buffalo River is considered to be one of Arkansas' greatest natural treasures; thus there is strong interest in protecting it from undue anthropogenic influences. A general description of the area within the Buffalo River Watershed was given by Smith (1967).

The initial digital characterization of several features within the Buffalo River Watershed was presented by Scott and Smith (1994). Their work resulted in the development of a geographical information system (GIS) database for the Buffalo River Watershed. Digital data layers developed for this database included soil taxonomic units, watershed and sub-basin boundaries, topography, physiographic units, and land use-land cover (LULC) for 1965, 1974, and 1979.

OBJECTIVES

The objectives of this work were to determine the spatial distribution of both the surface geology and the 1992 LULC within the Buffalo River Watershed. These digital data layers were developed and incorporated into the Buffalo River GIS database. A further objective of this work was to examine land use changes within the watershed over the years for which LULC data existed.

METHODS AND MATERIALS

This digital characterization of the Buffalo River Watershed was divided into two components: surface geology and land use-land cover during 1992. The methods used in quantifying the spatial distribution of these two attributes of the watershed are given below.

Surface Geology

Geologic attributes of the Buffalo River Watershed were developed in a digital format, partly at a scale of 1:24,000 and partly at a scale of 1:62,500. The scales of digitization were the same as the scales of the source maps. The source maps used depended on their availability and quality. Source materials were obtained from the Arkansas Geological Commission in Little Rock and consisted of 35 surface geology maps. Thirty-one of the source maps were drawn on 7.5-minute United States Geological Survey (USGS) topographic quadrangles at a scale of 1:24,000. The remaining four surface geology maps were drawn on 15-minute USGS topographic quadrangles at a scale of 1:62,000. The source maps had been reproduced on vellum. The location and names of these quadrangles within the watershed are shown in Figure 1. Information contained in the source maps consists of formation contacts and faults.

Several of the 7.5-minute source maps contained slight gaps due to having been cut and pasted before reproduction. This resulted in visible offsetting of topographic contours and map registration problems. Source maps having this problem included the quadrangles of Boxley, Murray, Fallsville, Swain, Marshall, Harriet, Canaan, Leslie, Oxley, and Onia (Figure 1). To resolve this problem, these source maps were completely redrafted onto mylar, using USGS 7.5-minute topographic quadrangles as a base. In addition, because the Ponca source map had been reduced from its original size, it was completely redrafted over the Ponca 7.5-minute topographic base so that it also could be digitized at a scale of 1:24,000. Other source maps had incomplete or omitted contacts and were completed by drafting the missing contacts directly onto the source maps, paying particular attention to the form and spacing of topographic contours and to stratigraphy.

The geologic maps were registered and digitized using the GRASS module v.digit. Prior to digitizing each map, a corresponding registration file was created using the GRASS command v.reg. These files contained mathematically generated coordinates of appropriate quadrangle corners. Once a map was secured on the digitizing table, it was registered to the points contained in its corresponding registration file. Residual mean averages below 2.0 for 1:24,000-scale maps and below 10.0 for 1:62,500-scale maps were accepted. Once properly registered, the maps were digitized by tracing the formation contacts and faults with the digitizing puck.

Edge matching between individual geology maps involved two main phases. First, adjacent source maps were placed alongside each other. At this stage, it was verified that contacts between adjacent maps were properly aligned across map boundaries. In many cases, however, contacts between maps did not match. Where this was a problem, adjustments were made by partially redrawing contacts such that they aligned properly. Decisions about redrawing the contacts were based on changes in topography and on stratigraphy. During this stage of edgematching, it also became apparent that differences in classification of the various stratigraphic units existed between geological maps in the watershed. A decision was made, therefore, to incorporate straight line segments along map boundaries to close off any areas whose classification did not continue across the map boundary. Classification differences between maps were usually a result of geologic units having been combined on one map but not on an adjacent map.

The second phase of edgematching began after all geology maps were digitized. Using the GRASS command v.digit, adjacent maps were viewed next to each other and edited to insure that there was a smooth continuation of contacts across map boundaries. A "half-way" rule of thumb was used for contacts found to be offset at map boundaries after being digitized. Contacts were moved half way at the edge of one map, and the rest of the distance at the edge of the adjacent map, to form a smooth transition across the boundary.

Once edge matching was completed, a copy of each digital geology map was made and designated as a faults map. Fault information was retained in these copies. The original digital geology maps were then edited to remove fault information, except in places where a fault or a portion of a fault formed a contact between geologic units. This resulted in a vector map layer containing only geologic contact information. Likewise, contact information was removed from the copies designated as faults maps, leaving a vector map layer containing only fault information.

The individual contact maps were patched together using the GRASS command v.patch, resulting in a continuous coverage of the geologic units in the watershed. Individual faults maps were patched together as well, leading to a continuous coverage of mapped faults in the watershed.

All areas in the patched geologic contact map were labeled with their geologic attributes using the area labeling option in the GRASS module v.digit. An attribute numbering system that assigns a four-digit code to each unit was used. The first digit of the code identifies the physiographic region of the unit; the Buffalo River watershed lies within the Ozark region and is identified with the number three. The second digit identifies the age of the unit, the third digit identifies formations or groups of formations within a particular age, and the fourth digit allows for further divisions of the formation or group of formations, where they are interpreted. For example, the Upper Mississippian Formations as a group, designated as Mpfb on the state geology map (Haley and Glick, 1993), are identified with a code of 3210, while the Pitkin Limestone, the uppermost formation within the Upper Mississippian Formations, is designated by a code of 3211. In each of these codes, the "three" in the first place of the code represents the Ozark region. The "two" in the second position indicates their age as being Mississippian. The "one" in the third position of the code identifies them as belonging to the Upper Mississippian Formations. The "one" in the fourth place of the Pitkin Limestone code designated it as a sub-unit within the Upper Mississippian Formations.

Once all areas were labeled, the vector map was converted to a raster map having a resolution of 30 meters using the GRASS command v.to.rast. This raster map was then reclassified to combine units that had been distinguished on source maps into their more general classes using the GRASS command r.reclass. The general classes are those found on the state map of 1993 (Haley and Glick, 1993). The resulting geologic map is displayed in Figure 2. The first raster map and the vector layer from which it was derived were retained and contain all geologic information present on the source maps, i.e., classes present prior to the reclassification procedure.

This current work is an improvement over the 1:500,000 scale digital state geology map developed previously by the Arkansas Archeological Survey and presented in Scott and Smith (1994). The improvements are primarily due to digitizing source maps of a larger scale, i.e., 1:24,000 and 1:62,500 as opposed to 1:500,000. This resulted in a more accurate output map.

1992 Land Use Land Cover

Land use-land cover of the Buffalo River watershed was characterized based on 1992 Landsat Thematic Mapper (TM) imagery. The raw imagery was stored as a part of the CAST statewide database. For this report, the purpose for the classification was to allow land use comparisons within the watershed between 1992 and the previous years for which LULC data in the watershed already existed. The years for which land use data existed are 1965, 1972, 1974, and 1979 (Scott and Smith, 1994). Unsupervised classification techniques were used on the 1992 TM imagery to determine the spatial distribution of the broad categories of agriculture, forest, water, and urban/barren. In addition, the category consisting of transportation, power, and communications was taken from classifications of previous years and incorporated into the 1992 classification. Unsupervised classification of imagery allows a computer algorithm to group image pixels into homogeneous clusters according to their spectral reflectances. Each of the resulting clusters is then assigned to a land use category by the analyst (Schowengerdt, 1983).

The TM imagery used for the LULC classification was recorded on the morning of October 10, 1992, and consists of seven seasonally corrected spectral bands. Bands 1, 2, and 3 are blue (0.45 - 0.53 um), green (0.52 - 0.6-0 um), and red (0.63 - 0.69 um), respectively. Band 4 (0.76 - 0.90 um) records the near-infrared portion of the spectrum. Band 5 (1.55 - 1.75 um) and band 7 (2.08 - 2.35 um) are shortwave infrared bands. Band 6 (10.5 - 12.5 um) is a thermal infrared band. Thematic Mapper imagery has a resolution of 30 meters.

Classification of the 1992 watershed TM imagery was accomplished using PCI v5.3 image classifying software. Two different unsupervised classification algorithms in PCI were utilized. The KCLUS algorithm uses the K-Means method to classify the image into different clusters. It is an iterative routine that begins with an initial set of spectral clusters. On the first iteration, each pixel in the image is assigned to the cluster whose spectral reflectance most resembles its own. This assignment results in a new set of spectral clusters, to which pixels are reassigned in the same way. The process is repeated until no further movement beyond a specified threshold occurs, or until a maximum number of iterations has been reached. The PCI ISODATA classifier uses the isodata method of classification. This routine is similar to the KCLUS algorithm but employs a more sophisticated set of heuristic techniques. Details about the K-MEANS and ISODATA methods of classification can be found in Tou and Gonzales (1974) and in the PCI v5.3 documentation.

Classification routines were run on the TM imagery three separate times. Although each run resulted in a classification that was regarded as good, each subsequent run was considered to be an improvement over the previous run. Results of the third run, therefore, were accepted as the final LULC classification of the imagery and are discussed in this report. The first run applied the KMEANS classifier to the TM bands, specifying an output of 50 clusters. The ISODATA classifier was used in the second and third runs and resulted in 100 and 159 clusters, respectively. In addition to the raw TM imagery, results from a tasseled cap analysis were input into the third classification routine. Tasseled cap analysis results in greenness, brightness and wetness components that are reached by weighting the TM bands differently for each component. Details of this procedure are available in the PCI v5.3 documentation.

Assignment of clusters resulting from the classification routines to land use classes was accomplished using the PCI v5.3 ImageWorks module. The image containing the clusters was displayed. A unique color was selected for each land use category to be classified, and, as clusters were assigned to categories, they were displayed in the appropriate color using the ImageWorks pseudo-color table. Throughout the process, the raw TM imagery was viewed in different band and color combinations. In particular, TM bands 4, 3 and 2 were viewed in red, green, and blue, respectively, to achieve a display similar to that of a false-color IR composite. Decisions about category assignments were influenced by several factors, including various sources of ancillary data.

To begin, coincidence reports between the clustering results and the 1979 and 1972 land use maps (Scott and Smith, 1994) were run. Clusters, which were accounted for entirely or almost entirely by a particular category in previous years, were generally assigned to that category. If any doubt existed as to the proper assignment of a cluster, a decision was not made until other factors were considered. Once as many clusters as possible were classified in this way, remaining clusters were assigned to categories using various strategies. A coincidence report was also run between the clustering results of the third classification routine and the classified image that was based on the second classification routine. This report was used in a similar way to aid in assigning categories to clusters of the final routine. Doing this was regarded as valid since, though spectral clustering resulting from the third run was the most refined, the second classification was thought to be a generally good one.

Field boundary data collected in 1992 (Smith, 1995) were available from the National Resources Conservation Service for an eastern portion of the watershed in a vector format. The main sub-basin areas for which these data were available are displayed in Figure 3. Because these data were collected near the time of the satellite imagery, they were extremely helpful in verifying the cluster assignments described above, particularly in verifying which clusters should or should not be included with the agricultural category. These vectors also were helpful in selecting additional clusters that had reflectances characteristic of agricultural lands.

General trends in the image became apparent once a sufficient number of clusters were assigned to categories and were displayed in the corresponding colors. Additional clusters could then be examined and classified based on association. Clusters that were not yet assigned to a category but were largely surrounded by a particular category (mainly agricultural or forest) were displayed separately in a unique color. If it appeared that most of the pixels from that cluster were in fact associated with a certain category, the cluster was assigned to that category.

Because urban and barren areas have similar spectral reflectances (both are very bright) and no ground truth was conducted, they were not separated when assigning categories. For example, when a cluster occurring in an urban area was assigned a unique color to distinguish it from its surroundings, it became apparent that pixels belonging to the same cluster also occurred along the Buffalo River in places where the classification of barren (i.e., sand or gravel bar) was far more reasonable. To select clusters for the urban/barren category, the known urban area of the town of Marshall was viewed with Digital Line Graph (DLG) road vectors overlain on the image. Clusters occurring within this area were highlighted using a unique color. The clusters that, when highlighted, proved to be associated only or mostly with the urban area, and usually with likely barren areas, were classified as urban/barren.

All 159 clusters from the third classification routine were assigned to one of the four categories of agricultural, forest, urban/barren, or water. After this was accomplished, it was observed that single pixels classified as urban were scattered throughout areas that were otherwise agricultural. This is not surprising since any type of building existing within an agricultural area, including poultry houses, could give an urban type of reflectance. It was also noted that some pixels classified as forest were scattered throughout agricultural areas, and vice versa. This is not surprising either, since small stands of trees may exist within fields, and since any shrubby vegetation existing within a field may contribute to a spectral signature closer to that of forested areas. To eliminate some of these isolated pixels, a sieve filter routine in PCI v5.3 called SIEVE was run on the classified image. The sieve filter aggregates isolated pixels into the largest surrounding category. Details about SIEVE can be found in the PCI v5.3 documentation.

Areas covered by water, e.g., the Buffalo River and its larger tributaries, were easily detected in the satellite imagery due to the imagery's 30-meter resolution, as well as to the distinctive spectral signature of water. Water has an extremely low near-infrared reflectance. DLG stream vectors were used to further confirm the areas thought to be covered by water. The result was a map having considerably more area classified as water than in any of the classification maps from previous years. This means that most areas, i.e., pixels, classified as water in the 1992 imagery were classified as other categories in the previous years of analysis. In order to keep this area constant across all years for comparison purposes, areas classified as water in the 1992 imagery, as well as in any of the previous years, were patched into the maps for every year. In doing this, the assumption was made that water coverage has not changed drastically over the time period being examined.

The category of transportation, power, and communications (primarily roads) was included in the earlier LULC maps (Smith and Scott, 1994). Not all these areas, however, were identified as such in the 1992 classification. It would probably be appropriate for some of the pixels belonging to clusters identified as urban/barren in the 1992 classification to be assigned to this category. In fact, linear trends of areas classed as urban/barren in the classified imagery were noted. These trends lined up well with DLG road data. Similar spectral reflectances, however, between urban/barren areas and roads did not allow separate clusters to be formed for each during the unsupervised classification. Again, in an effort to maintain a uniform comparison across all the years, areas assigned to the transportation, power, and communications category in any of the previous years were patched into the classification maps for all the years, including 1992. This decision resulted in slightly different areal statistics for the transportation, power, and communications category when compared with the results of Scott and Smith (1994).

RESULTS AND DISCUSSION

Characterization of the Buffalo River Watershed was determined by using GIS techniques to quantify the spatial distribution of the surface geology and the spatial and temporal aspects of the LULC. We begin with the surface geology and conclude with the LULC.

Surface Geology

The surface geology of the Buffalo River Watershed is shown in Figure 2, stratigraphy in Figure 3 and mapped lineaments in Figure 4. The drainage basin of the Buffalo River in northwestern Arkansas is underlain by Paleozoic strata ranging from Early Ordovician to Early Pennsylvanian in age. Ordovician through Early Mississippian units are composed dominantly of limestone and dolomite, with thin but widespread intervals of sandstone and shale. Sandstone and shale units dominate the Late Mississippian through Pennsylvanian succession. Limestone also occurs in these units but composes a volumetrically minor part of the section.

Middle Ordovician, Upper Ordovician, and Silurian units are well developed east of the Buffalo River drainage basin in north-central Arkansas. These units are truncated northwestward by a major erosion surface that developed prior to deposition of the Chattanooga Shale in Late Devonian time. Multiple unconformities between units of Middle Ordovician through Silurian age also contributed to their removal. In the eastern part of the Buffalo River drainage basin, only scattered remnants of these units exist. The units have been entirely removed in the western part of the basin, and strata of Devonian age rest directly on the Middle Ordovician Everton Formation. Two generalized stratigraphic columns are presented in Figure 4 to show a comparison between geologic sections in the eastern and western portions of the watershed. Thicknesses of rock units in the columns are not exact.

The areal extent of the combined geologic units in the watershed is presented in Table 1. These areas differ somewhat from those published by Scott and Smith (1994), since this current work was compiled from source maps of larger scales, i.e., 1:24,000 and 1:62,500. The larger scale is considered to be more accurate. These data show that the Boone Formation accounts for the largest portion of the watershed. The next geologic unit in terms of area is that of the Bloyd Formation plus the Prairie Grove Member of the Hale Formation. This unit is followed by the Upper Mississippian Formations, which includes the Batesville Sandstone, the Fayetteville Shale, and the Pitkin Limestone. Following this unit are the combined St. Peter and Everton Formations.

The lithologic characteristics of each geologic unit are discussed below. We begin with a discussion of the characteristics of the oldest units and proceed to the youngest units. The units are grouped according to the general map classes that resulted from the reclassification process, i.e., the units found on the state map of 1993. Each unit, however, is discussed individually.

Table 1. Areal extent of the surface geology in the Buffalo River Watershed.

Geologic unit	Acres	Percent of watershed
Powell Dolomite	4,543	0.53
St. Peter and Everton Formations	107,472	12.53
Upper and Middle Ordovician Formations	21,909	2.55
Silurian Formations	1,001	0.12
Boone Formation	307,800	35.89
Ruddell Shale	4,427	0.52
Upper Mississippian Formations	128,811	15.02
Cane Hill Member of the Hale Formation	41,598	4.85
Bloyd Formation, and Prairie Grove Member of the Hale Formation	186,304	21.72
Atoka Formation	53,741	6.27
Total Area	857,606	100.00

Ordovician System

Powell Dolomite

The Powell Dolomite is represented as a single mapping unit on all source maps on which it occurs. Some source maps, however, also depict a chert ledge occurring within this formation. In the reclassification process, the chert ledge was included with the Powell Dolomite.

The Powell Dolomite is a light-gray, fine-grained, argillaceous dolomite containing rare layers of concentrically banded nodular chert (McFarland, 1988), calcareous green shale, and at many places a conglomerate at its base (Croneis, 1930). It is Early Ordovician in age and ranges in thickness from 40 feet to almost 200 feet (McFarland, 1988). Exposed layers of the Powell Dolomite are somewhat rounded, and the rock breaks with conchoidal fracture into many small, angular fragments (Croneis, 1930). The Powell dolomite is disconformably overlain by the Everton Formation (McFarland, 1988).

Everton Formation and St. Peter Sandstone

The Everton Formation is Middle Ordovician in age and is about 250 to 350 feet thick. It has been divided into several members by various workers. The most prominent of these along the upper Buffalo is the 100-foot-thick Newton Sandstone Member of the middle Everton. This, like other sandstone units of the Everton, is a fine- to coarse-grained, well-rounded, frosted, often friable, well-sorted quartzarenite. Everton sandstones are cemented by dolomitic or calcitic carbonates, or by silica overgrowths. Above and below the Newton Member, the Everton consists of alternating beds of dolomite, limestone, and sandstone, none of which persist for any great distance laterally. Everton dolomites are very fine to coarsely crystalline and often include variable amounts of limestone and quartz sand. Everton limestones contain variable amounts of dolomite and quartz sand. Beds of quartz sandstone of the type found in the Newton Member occur throughout the interval. Discontinuous conglomerates, breccias, and cherts occur at various horizons in the Everton

(McFarland, 1988).

The Middle Ordovician age St. Peter Sandstone overlies the Everton Formation and is composed of well-rounded, medium, transparent quartz grains, cemented by a small amount of calcium carbonate. The rock is massive, friable, and porous (Croneis, 1930). The thickness of the formation ranges from a feather edge in the central part of the basin to over 175 feet in the east (Zachry, 1995). St. Peter Sandstone outcrops form bluffs that are conspicuous topographic features at many places (Croneis, 1930).

Plattin Limestone, Fernvale Limestone, and Cason Shale

The Middle Ordovician Plattin Limestone, which ranges in thickness from a feather edge to 250 feet, is a dense, even-bedded limestone occurring in both thin and thick layers. The limestone has a dominant blue-gray color and a homogeneous texture. At some places the formation is cherty, though it is in general free from chert (Croneis, 1930).

The Upper Ordovician Fernvale Limestone is a coarsely crystalline, massive, somewhat cross-bedded, medium, pinkish-gray, fossiliferous limestone (Croneis, 1930). Fossil components are mainly crinozoid fragments (Zachry, 1995). In places it reaches a thickness of 125 feet and contains lenses, nodules, and irregular masses of gray and brown chert (Croneis, 1930).

The Cason Shale is composed of calcareous shale and small amounts of sandstone, argillaceous limestone, phosphate rock, and a basal conglomerate that is made up of ferruginous phosphatic material, manganese oxide, some rounded quartz grains, and a few phosphatic, fossiliferous pebbles. Phosphate is widely disseminated throughout the formation, but at only a few places is it found in commercial quantities (Croneis, 1930). The unit ranges to 30 feet in thickness (Zachry, 1995).

Silurian System

Brassfield Limestone, St. Clair Limestone, and Lafferty Limestone

The Brassfield, St. Clair, and Lafferty Limestones are Silurian in age. The Brassfield Limestone in northern Arkansas is a light-gray, fossiliferous limestone. At most places it is granular and contains a small quantity of glauconite. This limestone is not more than 5 feet thick in the southern Ozarks (Croneis, 1930).

The St. Clair Limestone is a coarse-grained, highly fossiliferous, light-gray to pinkish-gray limestone. It is similar in appearance to the Fernvale Limestone, although it is lighter in color. The upper part of the St. Clair is bluish-gray and finer grained than the lower part; the basal beds are shaley. The formation in places reaches a thickness of about 100 feet. It is massive, and at many places on hillslopes it crops out in rounded masses (Croneis, 1930).

The Lafferty Limestone is an even-bedded, earthy, essentially unfossiliferous limestone, which becomes platy upon weathering. Most of this limestone is red, although the upper fourth is gray. It is in places 85 feet thick, though it is of small extent (Croneis, 1930).

Devonian System

Chattanooga Shale

The Devonian age Chattanooga Shale is a black, clay shale that breaks into thin plates and slabs and gives off the odor of petroleum when it is struck with a hammer. It ranges in thickness from a few inches to nearly 85 feet, but its average thickness is about 30 feet. The lower part of the formation is a black, carbonaceous, fissile clay shale that weathers into thin flakes. The upper part is lighter in color, slightly sandy, and contains considerable pyrite. The upper beds are less fissile than the lower beds, and they weather into well-defined prismatic blocks. The formation is at some places green, brown, or bronze colored, depending largely on the state of weathering and the quantity of carbonaceous material contained (Croneis, 1930). The Sylamore Member, composed of phosphatic sandstone, occurs at the base of the Chattanooga Shale (Zachry, 1995).

Mississippian Series

Boone Formation

The Lower Mississippian Boone formation consists primarily of limestone and chert, which vary in amount throughout the formation. It is of large areal extent and is generally between 300 and 350 feet thick in northern Arkansas (Croneis, 1930). The basal member of the Boone, the St. Joe Limestone, is a well-marked bed of gray to pink, very-fine to coarse-grained, fossiliferous, tabular-bedded limestone (Croneis, 1930) and contains some nodular and thinly bedded chert, as well as thin interbeds of calcareous shale (McFarland, 1988). The St. Joe Limestone, which ranges in thickness from a feather edge to about 100 feet, is exposed in practically continuous outcrop (Croneis, 1930). Its contact with the Boone is conformable and is generally marked by an increase in the volume of chert (McFarland, 1988).

Chert is dominant throughout the Boone Formation above the St. Joe Limestone, though it varies in volume both stratigraphically and spatially. Above the St. Joe, the Boone Formation is generally a fine-grained limestone with dark cherts. The upper parts of the Boone Formation are comprised of coarser limestones and light-colored cherts (McFarland, 1988).

Much of the unweathered chert of the Boone Formation is dense, hard, compact, and brittle and has a conchoidal fracture. Great quantities are left behind as regolith after the limestone has been dissolved by ground water. Because the limestone of the Boone is nearly pure calcium carbonate and is water soluble, groundwater has formed karst features such as underground drainage channels, fissures, caves, and sink holes (Croneis, 1930).

Ruddell Shale

The Ruddell Shale has historically been regarded both as an independent unit and as the upper member of the Moorefield Formation (Manger, 1995). According to Frezon and Glick (1959), the Ruddell Shale is a gray, fissile-clay shale that overlies the Moorefield Formation, a dark-gray limy shale and silty limestone. According to Zachry (1995) and Manger (1995), the Ruddell Shale generally is not easily distinguished from the underlying Moorefield Formation, and, although areas on source maps obtained for this study are labeled as Ruddell Shale, these areas should be grouped with the inclusive Moorefield Formation. Speaking of the Moorefield Formation as a unit including both the upper (Ruddell Shale) and lower member, Croneis (1930) states that it is dominantly a shale that is dark and fissile at many places and at other places sandy, containing thin layers of sandstone, limestone and, according to Manger (1995), chert.

Batesville Sandstone, Fayetteville Formation, and Pitkin Limestone

The Batesville Sandstone, Fayetteville Formation, and Pitkin Limestone are Upper Mississippian in age. The sandstone of the Batesville Formation is a brown, calcareous quartzarenite interfingered with a limestone member, the Hindsville (McFarland, 1988). The sandstone is generally medium grained. In fresh exposures the formation appears to be massively bedded, but its flaggy nature becomes apparent by weathering; beds more than 2 feet thick are rare. At some places the Batesville sandstone is prominently laminated and cross bedded. It is generally softer and thinner bedded in its lower part and harder and more massive above. Excluding the Hindsville member, the Batesville formation ranges in thickness from a feather edge to about 225 feet; its thickness increases toward the north and the east. The Batesville Formation is found along the base of slopes of the isolated hills and mountains north of the Boston Mountain escarpment (Croneis, 1930).

The Fayetteville Formation is a black, fissile, carbonaceous shale in the Buffalo River drainage basin (Zachry, 1995). The Fayetteville Shale ranges in thickness from 10 to over 400 feet and weathers to sticky red and yellow clays. The Upper Fayetteville Shale frequently contains beds of dark-gray, fine-grained limestone, and the formation contains locally abundant clay-ironstone concretions (McFarland, 1988).

The Pitkin Limestone is the uppermost formation of the Mississippian System in northern Arkansas. It consists of massive layers of compact, bluish-gray limestone that is ferruginous and porous at many places. The rock is rather sandy in places, and upon weathering it breaks down into angular blocks and thin plates. The Pitkin stands out at many places as a steep cliff due to the weathering of the non-resistant Fayetteville Shale beneath it (Croneis, 1930).

Pennsylvanian Series

Hale Formation and Bloyd Formation

The Hale Formation is composed of the Cane Hill Member below and the Prairie Grove Member above. The Cane Hill Member is composed of shale and interbedded siltstone and sandstone (McFarland, 1988) and is designated as a separate map unit on the state map of 1993. The unit ranges from 30 to 100 feet in thickness (Zachry, 1995).

The Prairie Grove Member of the Hale Formation is included with the overlying Bloyd Formation on the state map. Its basal contact with the Cane Hill is sharp and unconformable (McFarland, 1988). The Prairie Grove Member is a massively bedded calcareous sandstone with occasional beds of fossiliferous limestone. At places the unit is strongly cross-stratified (Zachry, 1995). Exposures of the Prairie Grove form prominent bluffs (McFarland, 1988). The Prairie Grove Member grades upward into a coarse bioclastic limestone that is lithologically similar to the overlying Brentwood Limestone Member of the Bloyd Formation. The contact between the Hale and the Bloyd is conformable but obscure (McFarland, 1988).

The Bloyd Formation is composed of shale with thin limestone units near the base and ranges to 200 feet in thickness (Zachry, 1995). The Brentwood Limestone Member of the Bloyd is generally separated from the Hale formation by 5 to 20 feet of black fissile clay shale, though at some places the shale is either covered or absent (Croneis, 1930). The middle Bloyd sandstone forms a prominent, intensively cross-stratified unit in the middle of the formation. The sandstone ranges from 30 to over 100 feet in thickness (Zachry, 1995).

Atoka Formation

The Atoka Formation rests unconformably on the rocks of the Morrow Group and is the youngest formation that crops out in the Boston Mountains. The Atoka Formation ranges in thickness from a feather edge to 2250 feet and consists of alternating beds of sandstone and shale, with a few beds of calcareous sandstone of small areal extent (Croneis, 1930).

The sandstone beds range in thickness from less than 1 foot to more than 125 feet and are variable in character. Most of them are medium-grained and light to dark brown in color. Many of the thinner sandstone beds are ripple-marked, and many of the thicker ones are cross-bedded. The thicker beds of sandstone grade upward from sandy shale to massive beds of sandstone and are so similar that no single bed can be traced over even a relatively small area (Croneis, 1930).

The shales of the Atoka Formation are black and carbonaceous, and although less fissile than those of the Fayetteville and Bloyd Formations, they closely resemble those beds. Many of the shaly layers form soft brown or drab clays (Croneis, 1930).

1992 Land Use Land Cover

The spatial distribution of LULC in the Buffalo River Watershed resulting from the partially classified 1992 imagery is presented in Figure 5. This map shows that the western- and eastern-most portions of the watershed were primarily forest with strips of pasture along the streams. Along the US highway 65 corridor, including the areas around Marshall and on toward Harrison, the intensity of pastures increased markedly.

Land Use Characterization

Land use characteristics of the Buffalo River Watershed were estimated for five LULC categories over a 27-year period of time. The land use results for 1965, 1972, 1974, 1979, and 1992 are presented in Table 2. One should keep in mind that the source materials for these data varied, possibly affecting the absolute area within a land use category. However, it is thought that the temporal trends that are evident from these data are real.

For all five years examined, forest represented the largest landuse in the watershed, followed by agricultural, i.e. primarily pasture, the combined urban and barren areas, and water. The areal extent of the first three land use categories changed temporally. The area in forest decreased while the areas in agriculture and urban/barren (except for 1979 data) increased during the 27-year period. For the purpose of keeping a uniform comparison across years, we assumed that the areal extent of water and of transportation, power, and communications had not changed significantly over the time period of study. Thus, these LULC data are slightly different from those of Scott and Smith (1994).

Table 2. Estimated land use characteristics of the Buffalo National River Watershed by year.

Landuse category	1965	1972	1974	1979	1992
	acres				
Forest	725,545	701,488	681,934	673,220	626,782
Agricultural	122,175	145,912	160,466	174,525	214,955
Urban and barren	2,562	3,481	5,097	3,063	9,175
Water	2,812	2,812	2,812	2,812	2,812
Transportation, power and communication	3,883	3,883	3,883	3,883	3,883

Linear Regression with Time

Regression techniques were used to quantify the temporal relationships between the areal extent in forest and in agriculture (pasture). The statistical analyses were made assuming that sampling began in 1965, i.e. time t equaled zero in 1965. The results, presented in Table 3, indicate that over the 27-year period of study, a linear decrease occurred in the acres of forest and a linear increase occurred in the acres of agriculture in the watershed. The slopes of these two regression lines were nearly equal in magnitude but opposite in sign, indicating that the annual decrease in areas of forest was approximately the same as the annual increase in acres of pasture. On the average, about 94.6% of the annual loss of forest area could be accounted for by the increase in pasture. Thus, in the Buffalo River Watershed, the primary conversion of the forests has been to pasture. In this analysis, the remainder was in the urban/barren category.

Table 3. Regression coefficients and coefficients of determination for the temporal relationships between forest and agricultural lands in the Buffalo River Watershed.

Category	Intercept	Slope	R^2
	acres	acres/yr	
Forest (F)	723,045	-3,619	0.982
Agricultural (A)	124,588	+3,423	0.990

The regression equations show that, if the annual rates of change in pasture and forest remain the same, by the year 2050 the area of pasture will equal the area of forest in the watershed, and that this area will be about 415,775 acres. At this time, the combined area of forest and pasture in the watershed would be about 831,550 acres, leaving about 26,100 acres for other land use categories.

Since the areal extent of both agricultural and forest categories were linear over time, we correlated the areas in these two landuse categories. The resulting relation could be described by the linear equation

$$F = 855{,}109 - 1.06 * A \qquad [1]$$

where F is the area of forest (acres) and A is the area of agriculture or pasture (acres). The correlation coefficient for this relation was -0.998, which is high. Thus, this indicates that the rate of change of forest and agriculture (i.e. pasture) was constant over time and approximately 1.05 acres of forest were lost per acre of pasture gained over the 27-year period.

Land Use Balance by Land Use Category

Changes in area in the watershed by land use category between 1979 and 1992 are summarized in Table 4 and shown in Figure 6. These results show that, over this 13-year period and within a given land use category, land use was dynamic. A land area balance was computed for the pasture, forest and urban/barren categories by accounting for the additions of land from other categories, losses of land to other categories and the land that remained in the same category. The changes in pasture, forest and urban/barren areas were quantified between 1979 and 1992. Of the 174,525 acres originally classified as pasture in 1979, about 4,720 and 52,276 acres had been converted by 1992 to urban/barren areas and to forest, respectively. This conversion represented 32.7% of the land area classified in pasture in 1979. Of the 673,220 acres classified as forest in 1979, about 3,724 and 95,845 acres were converted by 1992 to urban/barren areas and to pasture, respectively. This represented about 14.8% of the land area in forest in 1979. Of the 2,209 acres classified as urban/barren areas in 1979, 1,279 and 422 acres were converted to pasture and forest, respectively. These areas represented about 77% of the land area in the urban/barren category in

1979. Therefore, in terms of the percentage of the land area by category in 1979, the urban/barren areas were the most dynamic. However, in terms of land area within a land use category, the forest category was the most dynamic between 1979 and 1992. A greater area of forest was converted to pasture than area of pasture converted to forest. As a result, the area of forest in the watershed decreased and the area of pasture increased.

Table 4. Coincidence table of the changes in land use category between 1979 and 1992 in the Buffalo River Watershed.

Category	Category change to 1992	Area	Percent change in cover
		acres	
Agricultural (1979)		174,525	
	urban/barren	4,720	2.71
	agricultural	117,529	67.34
	forest	52,276	29.95
Forest (1979)		673,220	
	urban/barren	3,724	0.55
	agricultural	95,845	14.24
	forest	573,651	85.21
Urban/barren (1979)		3,063	
	urban/barren	731	23.87
	agricultural	1,576	51.45
	forest	756	24.68

The spatial distribution of the changes in LULC between 1979 and 1992 is shown in Figure 6. This map shows the locations of the land use changes during this time interval. It appears that the lands cleared occurred mostly in or near pastures and along streams. The reforested lands tend to occur in the more isolated areas of the watershed.

SUMMARY

The surficial geology of the Buffalo River Watershed was digitized and the areal extent of the various formations quantified. The Boone Formation accounts for the largest portion of the watershed, followed by the Bloyd Formation plus the Prairie Grove Member of the Hale Formation and the combined St. Peter and Everton Formations. The physical and chemical characteristics of these geological strata play a significant role in the quality of the waters within the watershed as well as in the characteristics of the soils and landuse.

Although the results of the LULC classification from the 1992 satellite imagery of the Buffalo River Watershed seem reasonable, they were largely based on clustering of "natural" groupings of reflectances. These results, which should be verified with ground truthing in the future, might result in different assignments of categories to the various spectral classes. A supervised classification should give results that reflect a truer classification of land use in the watershed. However, the trends in LULC indicate that the area in forest within the watershed is declining at a constant rate, the area in pasture is increasing at a constant rate, and the area classified as urban/barren is also increasing over time. Differences in the spatial distribution of LULC within the watershed were found. Some areas in the southern and eastern portion of the watershed have experienced little change

whereas other areas around Marshall and the US highway 65 corridor have experienced considerable change over the years.

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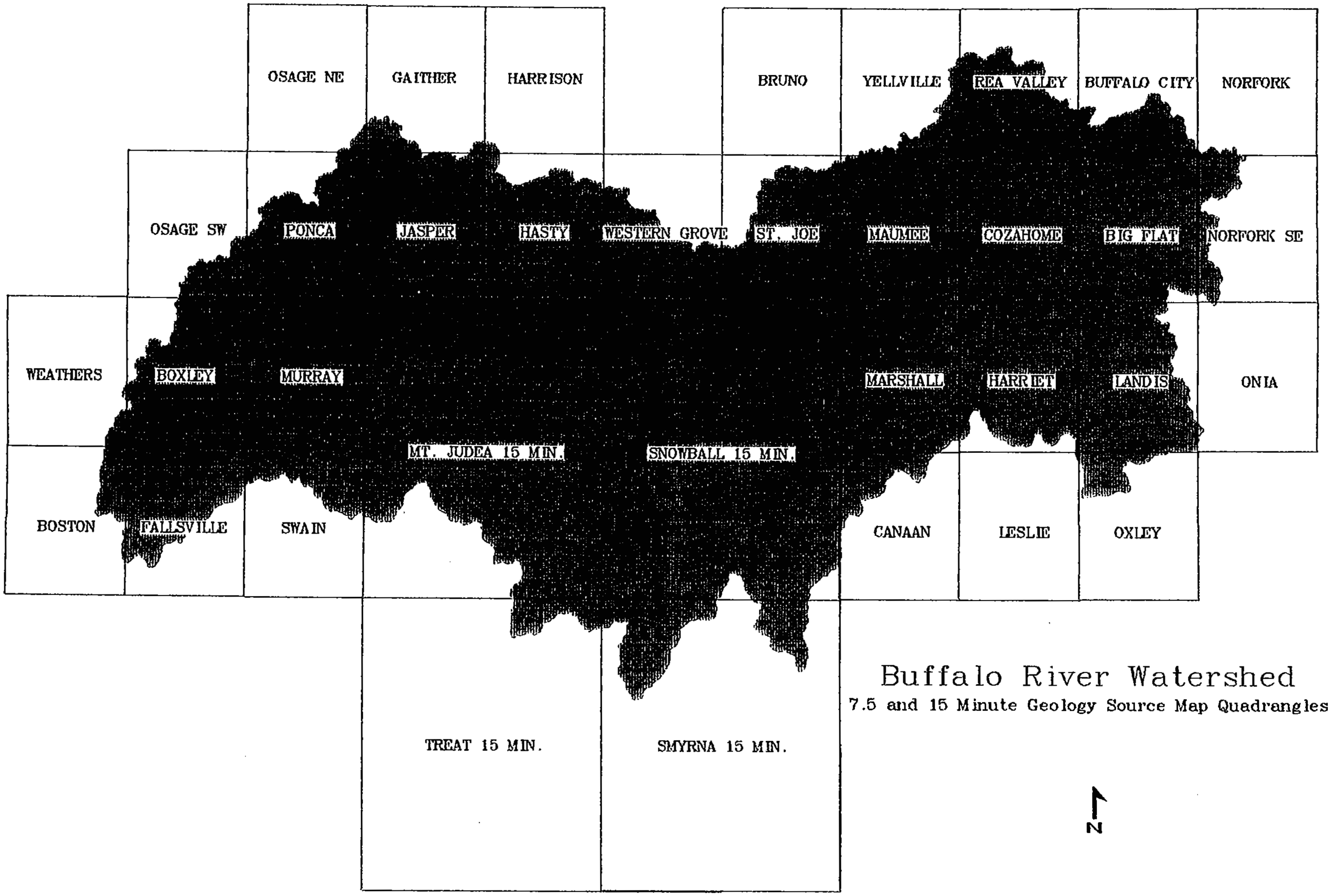
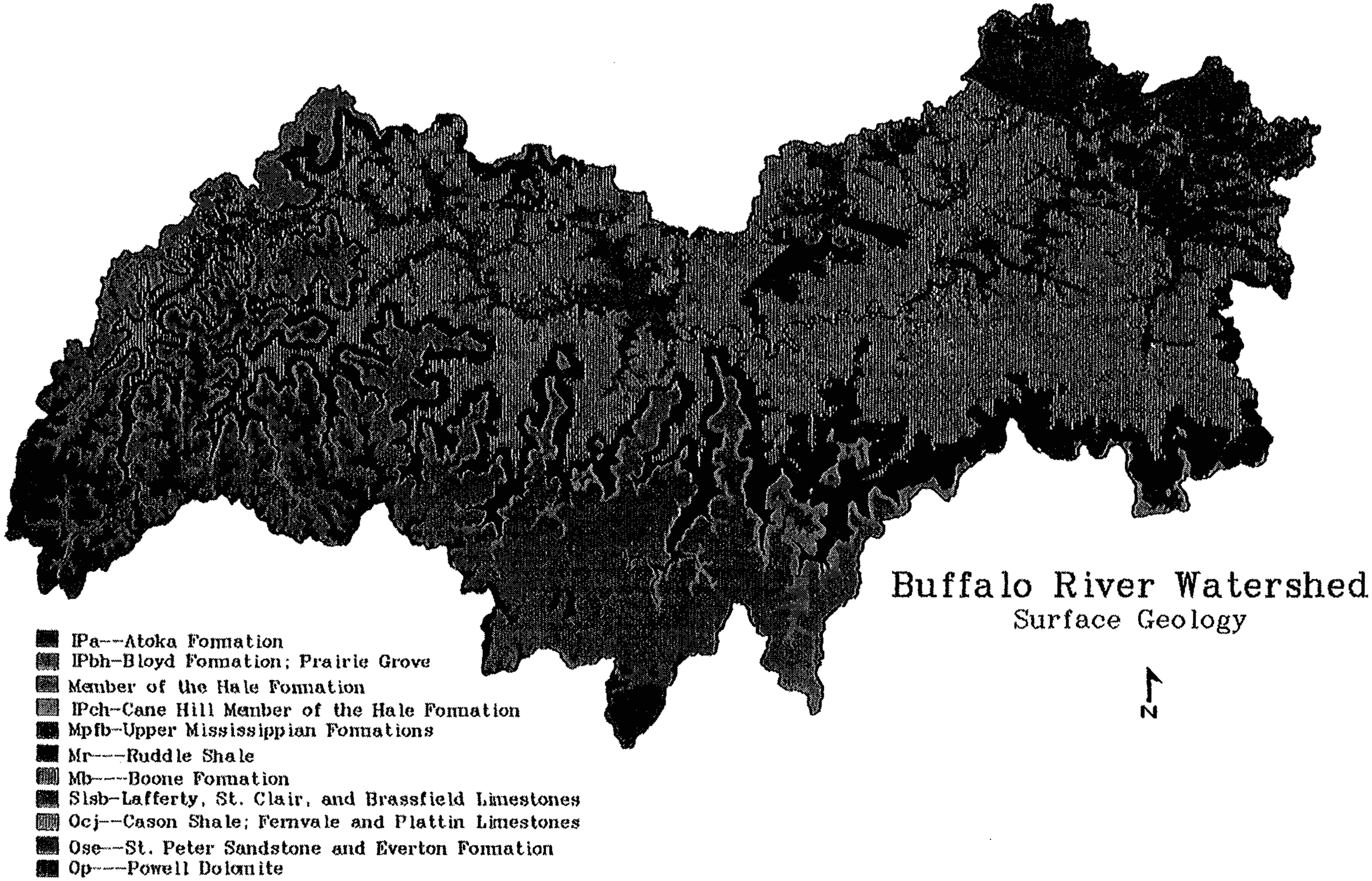


Figure 1. The USGS quadrangles used as source maps for digitization of the Buffalo River Watershed surface geology. Source: Arkansas Geological Commission.



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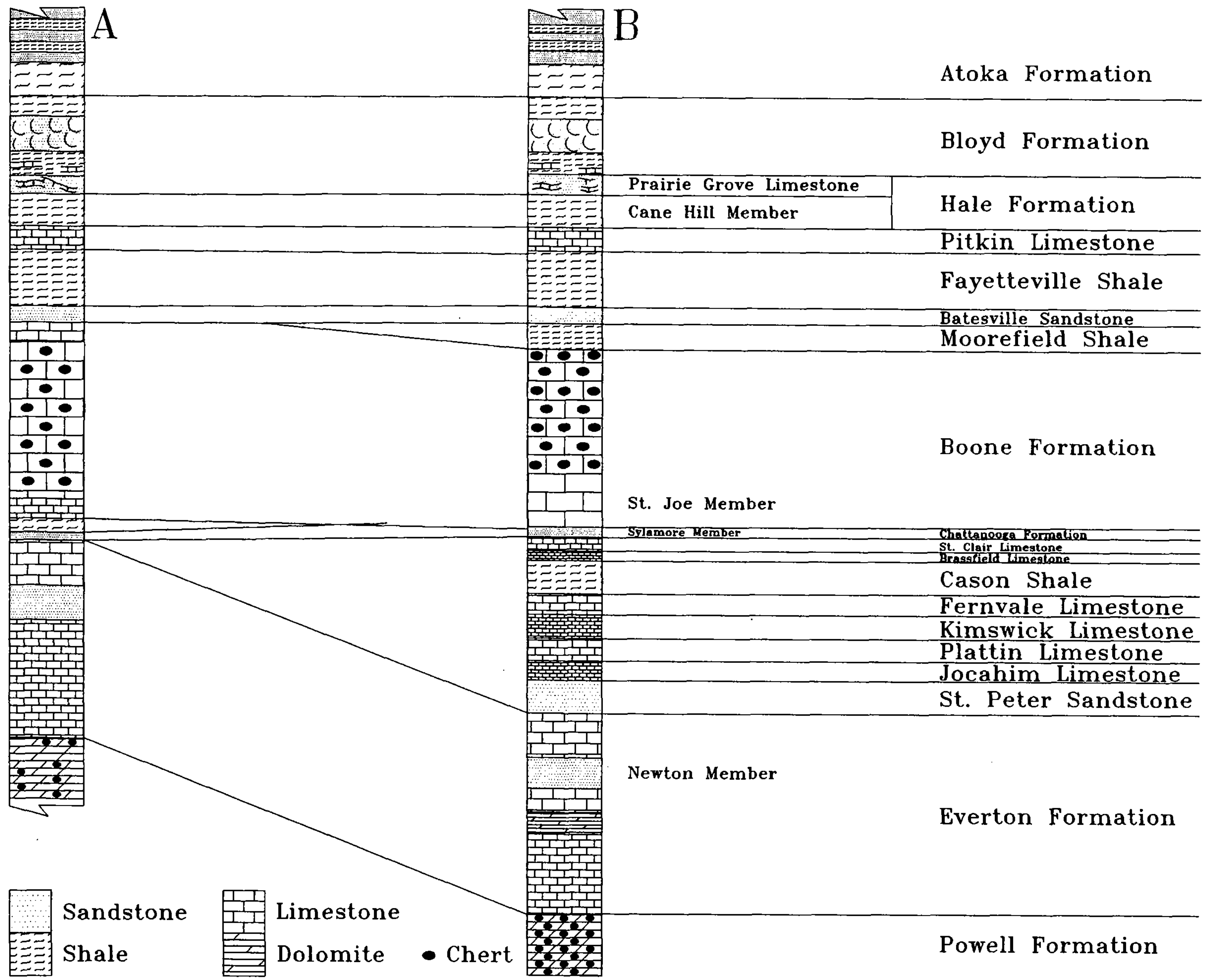

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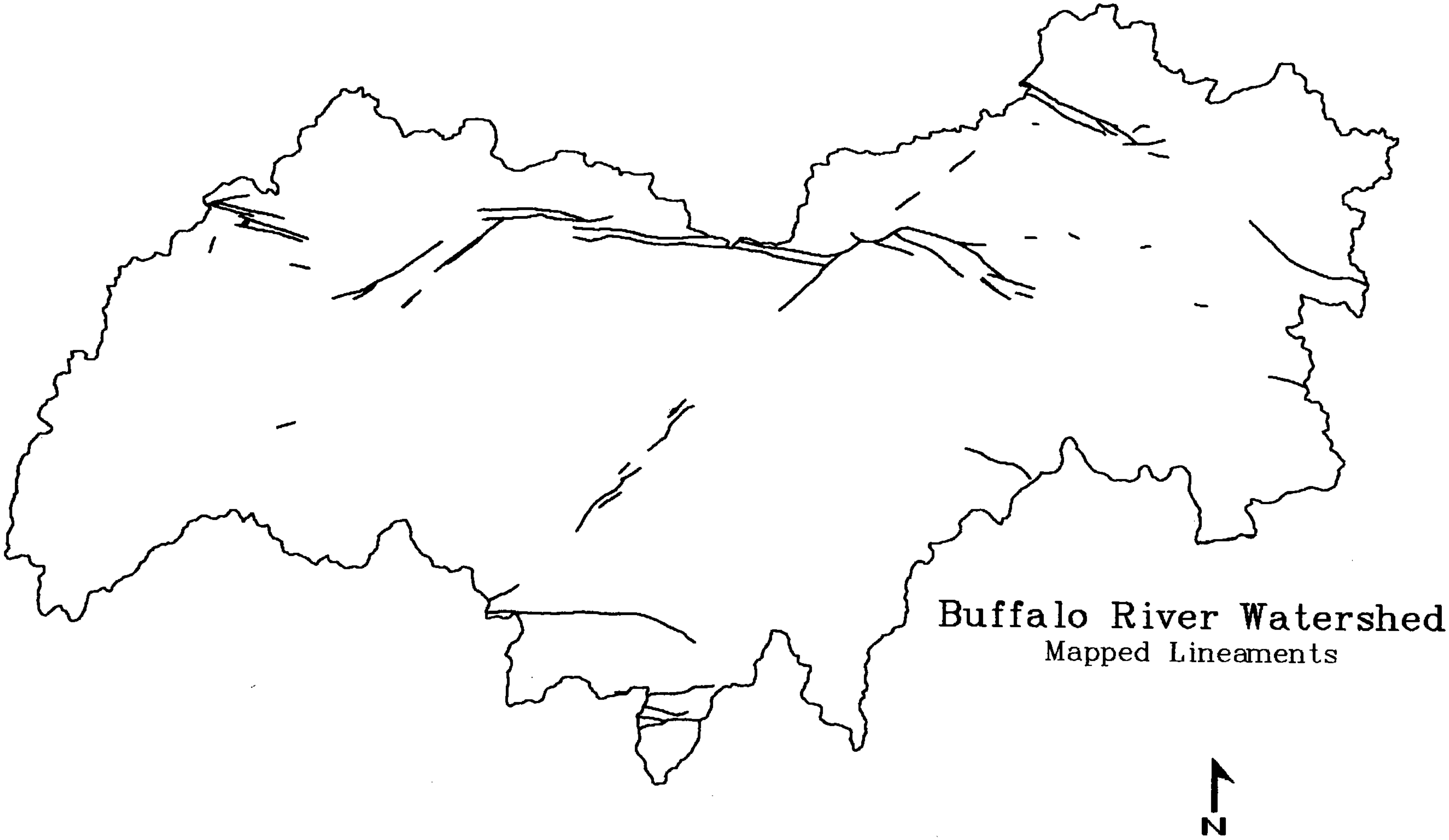

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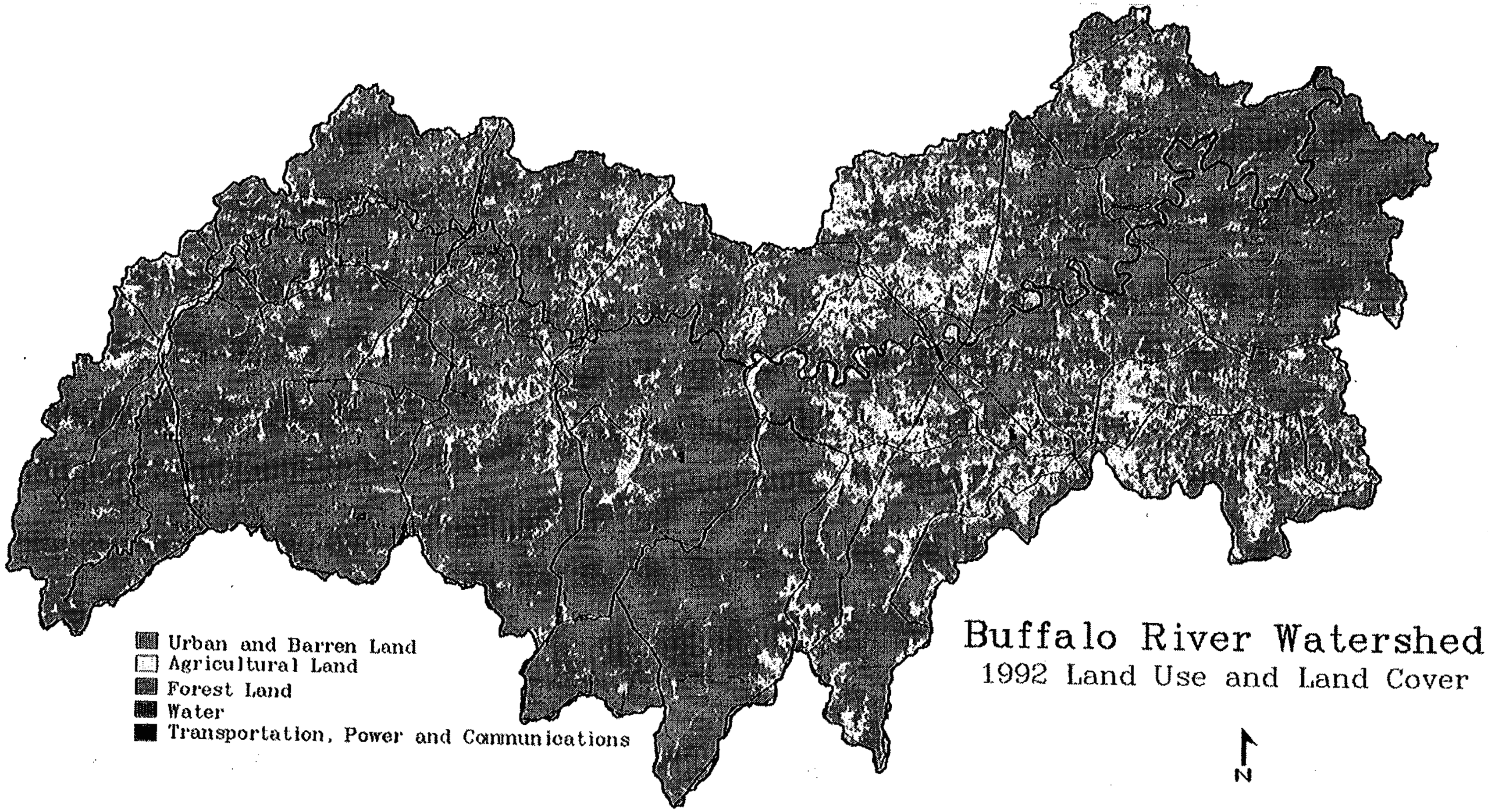

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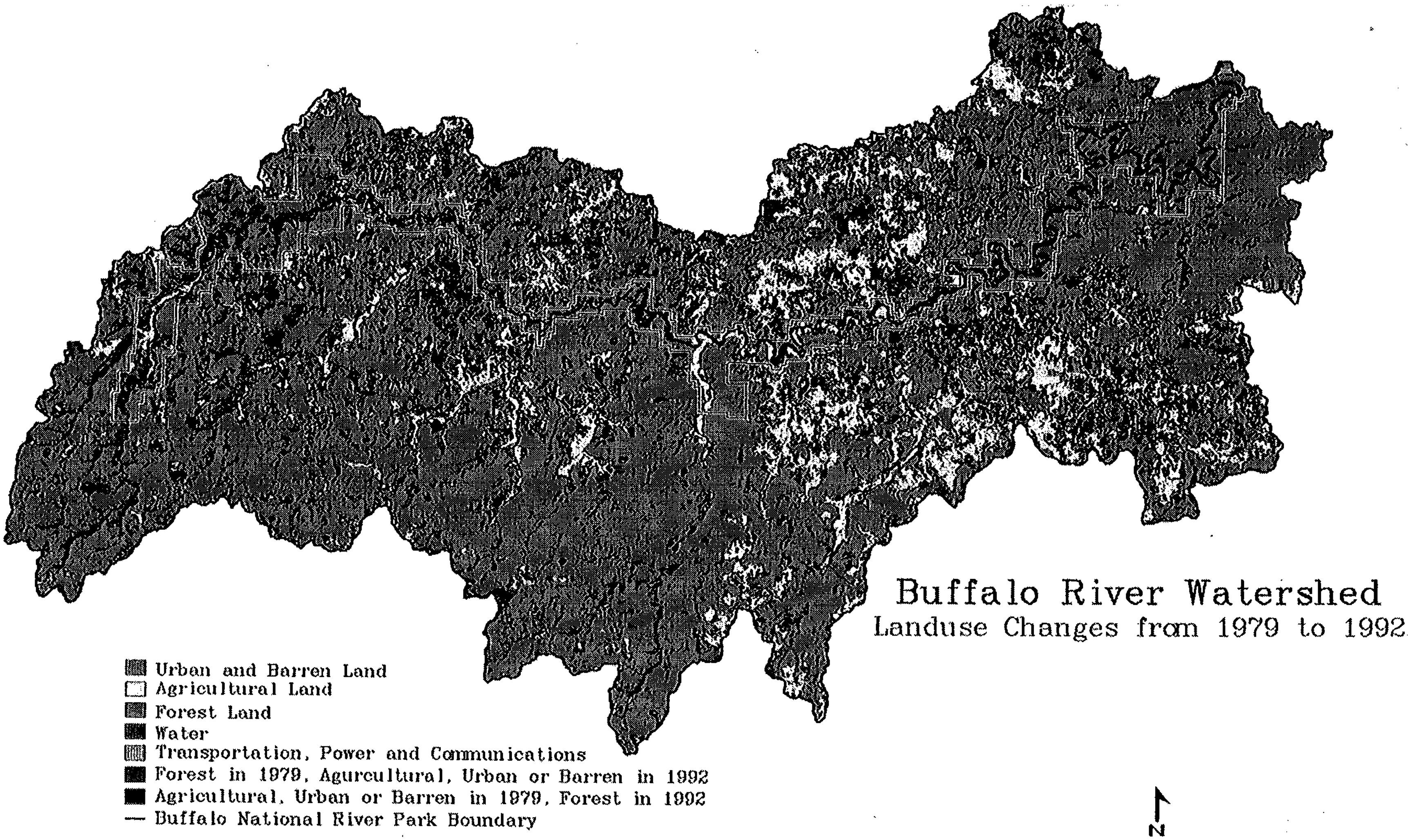

Figure 6. Land use changes in the Buffalo River Watershed between 1979 and 1992.